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DEEP-OCEAN BIODETERIORATION OF MATERIALS — PART II. SIX MONTHS AT 2,340 FEET

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DEEP-OCEAN BIODETERIORATION OF MATERIALS — PART II. SIX MONTHS AT 2,340 FEET

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by

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ABSTRACT

This is Part II of a series of reports on the biological deterioration of materials in the deep ocean. It covers the data obtained after exposing 2,385 specimens of 603 different materials for 6 months (197 days) on the Pacific Ocean floor at a depth of 2,340 feet (Test Site II). The materials were attached to a Submersible Test Unit (STU). The STU was retrieved in December 1964 and returned to the Laboratory for test and analysis.

There were marine fouling organisms attached to the plastic ropes, aluminum buoys, polyethylene-jacketed wire rope, nickel-plated shackles, and on some metal test specimens. Most of the plastic and all of the rope materials were covered with bacterial slime growth. Wood panels, plastics, and Manila rope were attacked by marine borers. Cotton and Manila rope specimens and jute-fiber burlap wrappings were severely deteriorated by bacterial action. Metal, glass, natural and butyl rubber, and some plastics with a smooth and extra hard surface were not affected.

The biological effects on materials recovered from Test Site II are briefly compared with materials recovered from Test Site I.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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PREFACE

The U. S. Naval Civil Engineering Laboratory is conducting a research program to determine the effects of the deep-ocean environment on materials. This research will be of great value in establishing the best materials to be used for deep-ocean construction in the Navy's conquest of "inner space."

A Submersible Test Unit (STU), on which many test specimens can be mounted, was designed for the purpose. The STU can be lowered to the ocean bottom and left for long periods of exposure. Planned exposures range from 4 to 48 months at depths of 2,500 to 18,000 feet.

Thus far, two deep-ocean test sites have been selected. Test Site I (nominal depth of 6,000 feet) is approximately 81 nautical miles southwest of Port Hueneme, California. Test Site II (nominal depth of 2,500 feet) is 75 nautical miles west of Port Hueneme. Additional test sites at depths of 12,000 and 18,000 feet will be chosen.

Various studies concerning the deep ocean will be reported, including (a) causes and rates of corrosion and changes in physical properties of metals and alloys, and degradation of nonmetallic materials; (b) physical and chemical parameters of sea water; and (c) biodeterioration of materials. In addition, techniques and equipment for emplacing, relocating, and retrieving STU's will be reported.

INTRODUCTION

As part of a research program to determine the effects of the deep-ocean environment on various engineering materials, the U. S. Naval Civil Engineering Laboratory in March 1962 placed the first of a series of Submersible Test Units, designated STU I-1, on the ocean floor in 5,300 feet of water at Test Site I. Since then three additional Submersible Test Units, designated STU's I-2, I-3, and I-4, have been placed on the ocean floor at Test Site I (Figure 1). In February 1964 after 4 months in the sea, STU I-3 was retrieved for study. It was loaded with 1,324 test specimens of 192 materials. The effects of deep-sea marine fouling and boring organisms upon these materials has been reported in Reference 1.

STU's II-1 and II-2 were placed on the ocean floor at Test Site II (lat 34°06' N, long 120°42' W), (Figure 1). Figure 2 shows the STU II-1 complex emplaced.[2] STU II-1 was recovered in December 1964 after 197 days on the ocean floor. This report presents the materials and methods employed for attracting, collecting, and evaluating deep-sea fouling and boring organisms and the results of field and laboratory investigations of the materials recovered from STU II-1. A literature survey has been published on fouling and boring organisms and their effects upon various materials submerged in the deep ocean.[3]

RESEARCH METHODS

Oceanographic Information

Concurrently with the STU program, numerous oceanographic and biological data-collecting cruises to Test Sites I and II have been conducted. These have produced information about the environmental parameters, such as salinity, temperature, oxygen content, and biological activity. Such information is essential in evaluating changes in the materials, especially corrosion of metals, exposed on the ocean floor. The environments at both test sites are summarized in Table I.[4,5]

Because the rate of corrosion of certain metals and alloys submerged in the sea are greatly influenced by the amount of dissolved oxygen concentration in sea water, it was desired to also investigate the effects of the minimum oxygen zone upon these materials. Test Site II was selected because at this site, at a depth of about 2,500 feet, the dissolved oxygen content in sea water falls to a relatively low value and is

known as "the minimum oxygen zone." Below and above this depth, the dissolved oxygen content starts to increase. The underlying causes of the minimum oxygen zone are still imperfectly understood.

Biological Activity

Rock Samples. Rock specimens were desired from this area to study any fouling organisms attached to the rocks, since they could be expected to attach themselves to other materials placed there. Prior to placing the STU at this site, a pipe dredge — a 10-inch-diameter by 36-inch-long steel pipe with retaining rods welded across the lower end of the pipe — was lowered to the ocean floor from an oceanographic vessel, USNS DAVIS, and the area dredged for rock specimens. Several passes were made across the area but no specimens could be obtained.

Sediment Samples. Marine bacteria are one of the major biological agents in the deterioration and fouling of various materials and equipment submerged in the sea. To determine the type and activity of bacteria in this deep-ocean area, sediment samples for bacteriological and biological analysis by standard microbiological methods[6] were obtained with:

1. A gravity core sampler, which takes cores up to 4 feet long.
2. NCEL's scoop-type bottom sampler, which collects about 225 cubic inches of sediment from a soft bottom.
3. A modified ZoBell bacteriological sampler, used to collect a mixture of sea water and sediment.[1]

Approximately 1,500,000 aerobic and 5,000 anaerobic bacteria were found in a gram of sediment (net weight) collected at the sediment-sea water interface. Sulfate-reducing bacteria were also present in the samples. The sulfate reducers are anaerobic bacteria which obtain their energy by the reduction of sulfate and sulfites in water in the absence of free oxygen. The end product of their metabolic process is hydrogen sulfide (H_2S). These microbes are considered to be responsible for the anaerobic corrosion of metals.

The sediment samples obtained with the scoop sampler were washed through a screen to collect mud-dwelling organisms. The animals were bottled and preserved in a 5-percent glycerol-alcohol solution for laboratory analysis.

A variety of animals were found in these samples. Amphipods and annelids were the most abundant marine organisms collected in the vicinity of STU Test Site II (Figures 3 and 4).

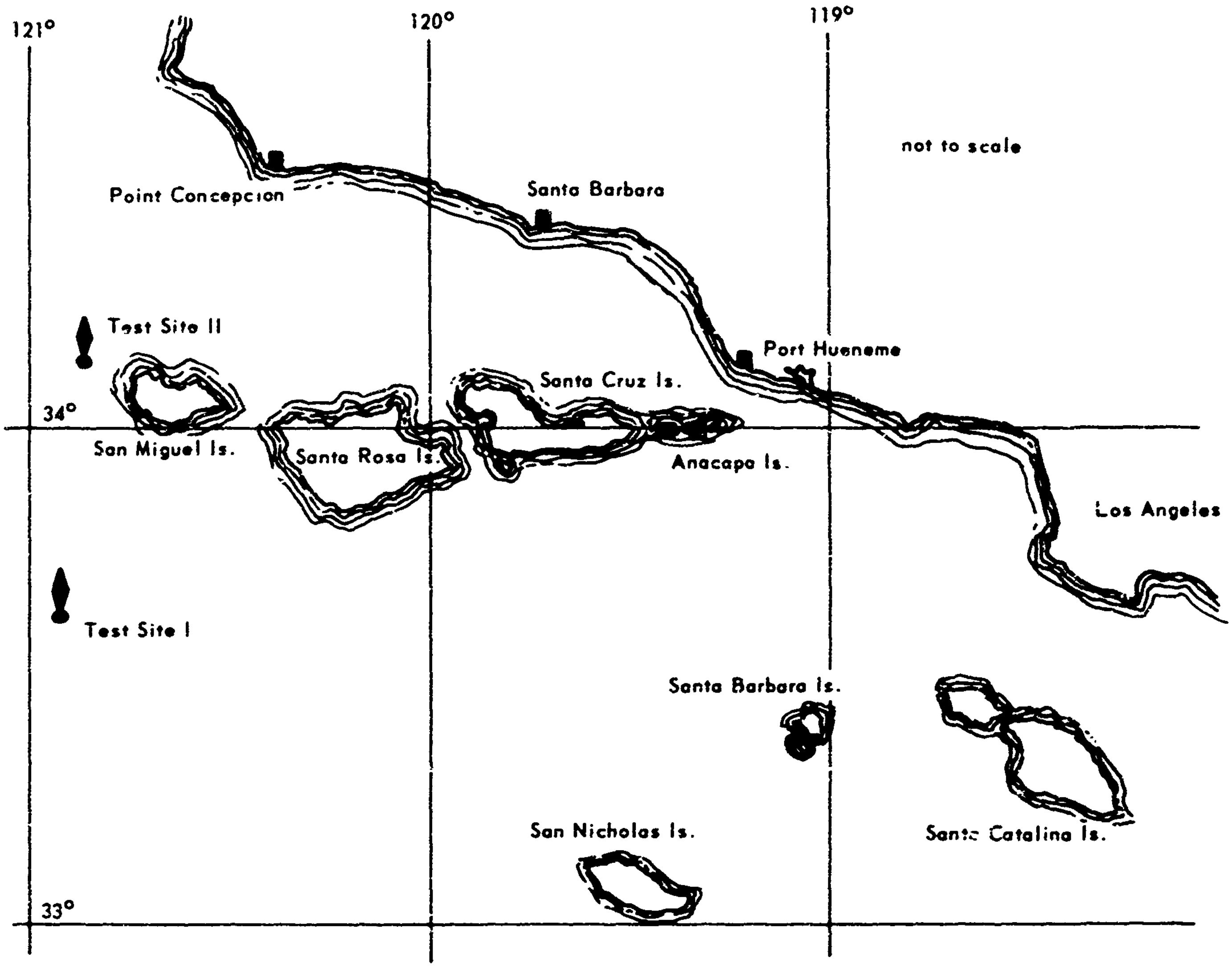

Figure 1. Test Site I (nominal depth of 6,000 feet) and Test Site II (nominal depth of 2,500 feet).

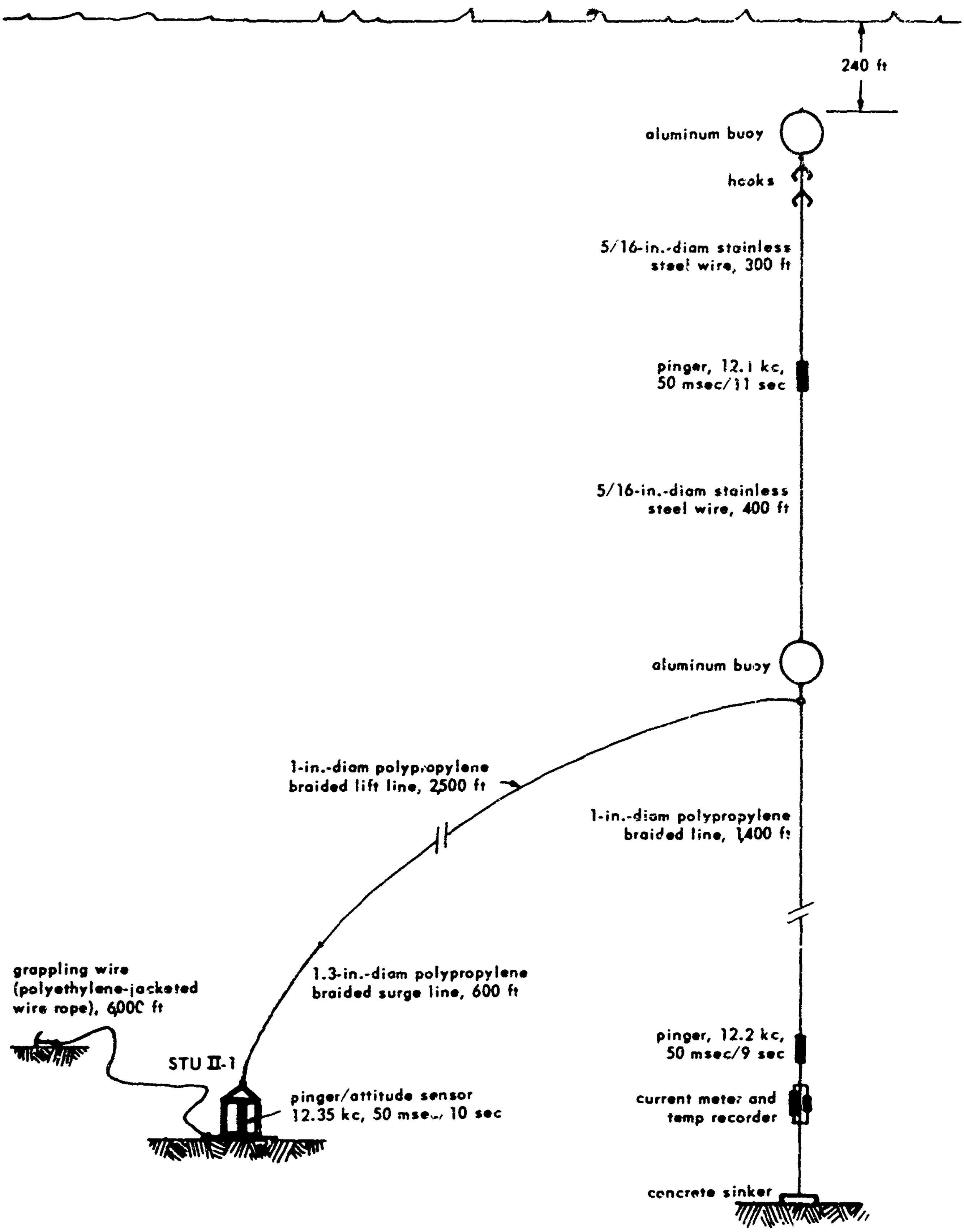

Figure 2. Schematic of STU II-1 on the ocean floor in 2,340 feet of water.

Table I. Summary of Environments at Test Sites I and II

Factors	Surface Water	Test Site I	Test Site II
Depth, ft		5,300	2,340
Temperature, °C	13.0	2.53	7.2
Dissolved oxygen concentration, ml/L	5.6	1.26	0.42
Salinity, o/oo (ppt)	33.6	34.56	34.37
pH	7.9 - 8.0	7.44	7.46
Hydrostatic pressure, psi		2,500	1,030
Current, knots		Less than 0.5	0.3 max
Sediment		Green mud containing glauconite, foraminifera, quartz, etc.	Green mud containing glauconite foraminifera, quartz, etc.

Figure 3. Amphipods and a cumacian (center) found in sediment samples.

Figure 4. Annelid worms found in sediment samples.

Test Materials

Test specimens numbering 2,385 items representing 603 materials were attached to the STU for the exposure test. For evaluating deep-sea biological effects on non-metallic specimens, two aluminum racks (bio-racks) were attached to the STU. Each rack held several plastic rods and tubes 3 feet long, and a 12- by 30- by 1/8-inch laminated phenolic plastic sheet. Numerous smaller test specimens were attached to the plastic sheet; one sheet was secured to the upper section of a bio-rack, and an identical sheet was secured to the bottom. In order to expose the test materials to biodeterioration in mud as well as water, the two racks were attached to the STU so that the lower portions would be buried in the bottom sediment and the upper portions exposed to sea water about 3 feet above the mud line (Figure 5).

The bio-rack specimens, listed in Appendix A, were carefully selected and prepared for deep-sea exposure. The 2- by 6- by 1/2-inch wood panels were cut from sound lumber, and the surfaces were cleaned with an alcohol solution and then covered with plastic to avoid contamination. The plastic covers were removed just before the test specimens were submerged. The wood panels were employed to collect specimens of any deep-sea fungi and marine borers which may have been present on the ocean floor.

The sections of the 3-foot-long plastic rods, tubes, and pipe, and rubber tubes were treated in different ways. One section of each specimen was roughened, a second section was wrapped in burlap, a third section was taped with plastic and rubber electrical tape, and the fourth was left smooth. The various wrappings were to provide a favorable foothold for the attachment and growth of deep-sea fouling and boring organisms. A large piece of untreated fir wood was fitted around both ends of each specimen to act as bait to attract and lead borers into direct contact with the specimen materials.

Four different kinds of rope, such as synthetic plastic fiber rope (nylon and polypropylene) and natural fiber rope (cotton and Manila), were placed on the bio-racks. Electrical cables covered with rubber or plastic insulation of various thicknesses were also placed on the racks. A small pine wood piece was fitted around each cable specimen to act as bait for marine borers. Another group of electrical conductors placed on the bio-racks consisted of 0.015-inch-thick insulation over a No. 16 tin-coated copper wire. The materials used in the formulation of the insulation is presented in Table II. The wire specimens were 15 inches long. Some were stressed (coiled) and some were nonstressed (straight). Stress was applied by coiling a 15-inch specimen lightly around a 1/4-inch-diameter glass rod and then removing the rod. Both ends of each specimen were sealed with two coats of rubber cement. The specimens were positioned so that one set of ropes and electrical cables would be buried in the sediment (in which bacteria are ordinarily most active), and an identical set would be exposed about 3 feet above the sediment.

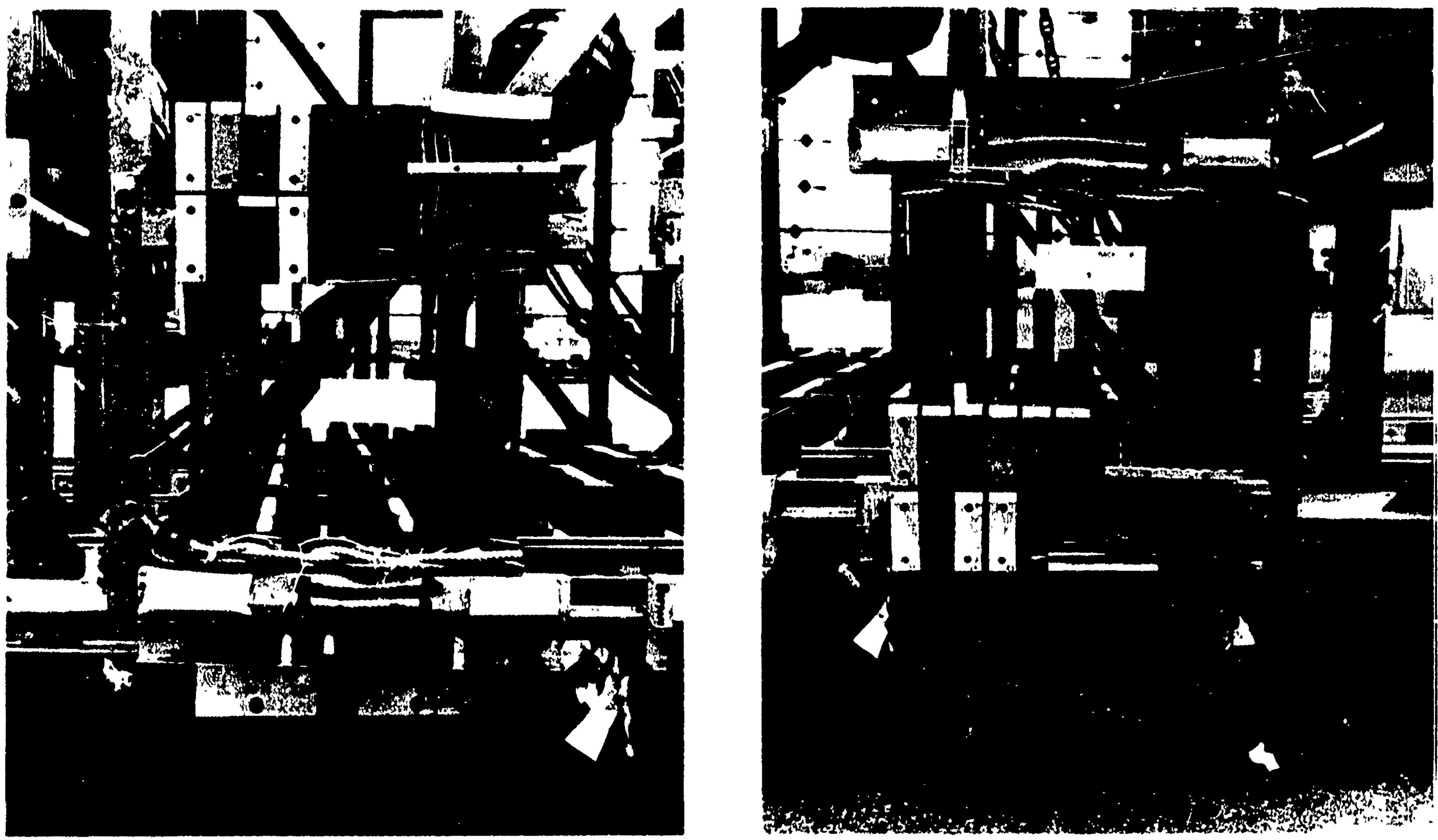

Figure 5. Materials assembled on bio-racks. The racks are attached to the side of a STU ready for exposure in the deep-ocean. One set of ropes and wood panels are for exposure in the mud while another set of identical materials are for exposure above the mud line in water.

Table II. Materials Used in the Formulation of Insulating Materials

Test Specimen	Plasticizer	Filler	Antioxidant
Polyethylene (standard polyethylene insulation)			
Polyvinyl Chloride (PVC)			
GR-S (SBR)	Cumarone-indene resin and microcrystalline wax	Hard clay and water-ground whiting	Polymerized trimethyl dihydroquinoline
Silicone rubber			
Neoprene (Type W)	Light process oil and petroleum	Hard clay	4, 4 thiobis (6-tert-butyl m-creosol)

Materials containing antifouling paints or other toxic substances were excluded from exposure aboard the STU. The current velocity at a depth of 2,340 feet was not great enough (approximately 0.3 knot) to carry away any toxic substance which might alter the natural biological fauna found in the immediate vicinity of the STU.

RESULTS

Marine Growth on STU Complex

The upper buoy of the vertical riser line was submerged approximately 240 feet below the surface of the water, the lower buoy approximately 940 feet below the surface (Figure 2). A fairly dense attachment of hydroid growth over the upper half section of each of the two aluminum buoys was observed when they were recovered (Figure B-1 in Appendix B). A 2-inch-long pink-colored coelenterate (possibly a sea anemone) was also securely attached to a buoy (Figure B-2).

A large number of pink sea anemones, up to 3 inches in diameter at the base, were found securely attached over the entire 6,000-foot length of polyethylene-jacketed 1/2-inch-diameter wire rope (Figures B-3 and B-4). The jacketed wire rope was attached to the STU frame and stretched across the ocean floor to serve as an alternate method of retrieving the STU by means of grappling.

Marine Growth on Test Materials

As soon as the recovered STU was placed on the deck of the ship (Figures B-5 and B-6), the test panels were examined for attachment organisms and these were photographed. The fouling animals were then carefully lifted from the test specimens and preserved in a 5-percent glycerol-alcohol solution for further analysis in the laboratory.

The test specimens at the bottom of the STU had been buried in sediment as planned as evidenced by traces of mud found at two corners of the frame.

There were several hundred amphipods (Figure B-7) about 3/8 inch long swarming over the materials on the bio-rack. It is possible that several thousand other amphipods may have been washed off during recovery of the STU. In addition to the amphipods, about two dozen small crabs were also found crawling over the materials on the bio-rack (Figure B-8). One was found wedged in between metal test specimens.

There were no signs of typical attachment organisms such as bryozoa, barnacles, or tube worms on any of the metal test specimens. Portions of hydroid colony (branches) were caught on the surface of most of the metal specimens, and there was a cluster of grapelike yellow growth (Figure B-9) securely attached to the surface of a metal panel.

A heavy bacterial slime growth covered the entire surface of a 3-foot-long flexible black vinyl tube (NCEL No. 374). This tubing may contain some chemical compound preferred by microorganisms as a source of food; there was only light slimy bacterial growth on the other plastic materials. The burlap wrapping on all the plastic rods and tubes was covered with bacterial slime; the fibers were deteriorated by bacterial action and could be easily torn apart by hand. A few marine borers were found burrowing into the jute fibers.

Electrical Tape Specimens

All of the plastic electrical tape which was wrapped around the plastic rods and tubes was attacked by marine borers except the tape over vinyl tube No. 374. Most were found boring along the edge of the overlap (Figure B-10 and B-11), and a few were found boring into the tape away from the edge. This indicates that the borers preferred to settle and start boring in a protected area along the edge of the tape where there was very little disturbance from water currents.

The borers did not penetrate the plastic tape and into the solid plastic materials underneath. The deepest borer holes showed that some had penetrated approximately three quarters of the way through the 0.010-inch-thick electrical tape.

Rope Specimens

A heavy growth of slime bacteria was present on the surface of nylon, polypropylene, cotton, and Manila ropes (Figure B-12). The fibers of cotton rope were decayed considerably by bacterial action. The cotton fibers were easily pulled apart by tweezers or one's fingers. Because of the damaged fibers, considerable difficulty was experienced attempting to place a splice at each end of the cotton rope for a breaking-strength test (Figure B-13). Only a few marine borers were found on the cotton, resulting in little damage to the fibers by borers.

Manila rope specimens were severely damaged by marine borers. The fibers were severed completely by the boring action of small borers. The 1/2-inch-diameter Manila rope was so heavily infested with borers deep inside the rope that it was impossible to count the numbers present. It was estimated that there were several hundred per lineal inch of the entire length of two 5-foot rope specimens (Figure B-14). In addition to the borers, slime bacteria were responsible for the decay of fiber materials.

A splice could not be placed on the Manila rope specimen for a breaking-strength test because of the deteriorated condition of the rope. However, by examining the damage to the hemp fibers, it was estimated that 75 percent of the tensile strength of the rope was destroyed. The deterioration of fishing nets and ropes made of natural fibers has always been a serious problem. It has been recognized that microorganisms are the primary cause of decay of fibers, resulting in loss of tensile strength. The microorganisms responsible are chiefly cellulose-decomposing bacteria.

Examination of the nylon and polypropylene ropes under a microscope showed that the fibers of these ropes were not decayed by microorganisms or severed by marine borers. On the contrary, the fibers were in excellent condition. Table III compares the breaking-strength tests of the exposed rope specimens with that of unexposed specimens.

Plastic Specimens

The 3-foot-long solid plastic rods and flexible tubes after 6 months of exposure are shown in Figure B-15. Plastics not deteriorated by marine organisms are noted later under the heading Unaffected Materials.

Cellulose Acetate Rod. Ten borers had penetrated into the solid plastic along the edge of the plastic electrical tape wrapping. The depth of penetration was about 1/64 inch, and the diameter of the largest borer hole was about 1/32 inch. A few borers had also penetrated slightly into the smooth and roughened areas of the rod.

Polystyrene Rod. About 25 borers were found boring into the solid plastic along the edge of the tape wrapping. The highest concentration of borer holes was found on the lower 2-1/2 inches of the smooth area of the rod exposed near the sediment. Approximately 100 small borer holes in a 1-square-inch area were found. In addition, a few borers were also present on other exposed areas of the plastic.

Table III. Breaking Strength of Rope Specimens Before and After Deep-Sea Exposure

Rope	Diameter (in.)	Breaking Strength (lb)	
		Before Exposure 1/	After Exposure 1/
Cotton	1/2	1,340	590
Manila	1/2	2,068	2/
Nylon	1/4	1,900	1,560
Polypropylene	5/16	1,810	1,760

1/Average of 2 ropes

2/Estimated 75 percent of tensile strength of rope destroyed by marine boring organisms.

Extruded Acrylic Rod. Approximately 150 borer holes were present around the solid plastic along the edge of the tape wrapping (Figure B-16). A few had started to penetrate into the smooth and roughened areas of the rod. One of the holes started in the smooth area was about 1/16 inch wide and 1/32 inch deep.

Cast Acrylic Rod. Only three borers had penetrated into the acrylic rod along the edge of the plastic tape wrapping. There was evidence where numerous borers had attempted to penetrate into the smooth and roughened areas of the rod.

Delrin Rod. A few borers had made very slight indentations on the surface of the plastic along the edge of the plastic tape wrapping.

Vinyl Tube (NCEL No. 388). Fifteen borers had penetrated into the vinyl tube along the edge of the plastic tape wrapping. The borer hole with deepest penetration was about 1/32 inch. Approximately 100 shallow borer holes per square inch were found on the lower 2-1/2 inches of the tube exposed near the sediment.

Vinyl Tube (NCEL No. 374). A heavy slimy bacterial growth covered the entire surface of the black flexible vinyl tube, including the burlap, rubber, and plastic wrappings. There was no sign of marine borer attack on the tube and wrapping materials. The heavy slime growth may have prevented the borers from establishing a firm foothold. After the tube was recovered and stored in a building at ambient room temperature for 3 weeks, a heavy growth of fungi developed over most of the exposed area.

Vinyl Tube (NCEL No. 387). The borers did not penetrate into yellow vinyl tubing; however, about 150 borers per square inch of surface had attempted to penetrate into the plastic on the lower 2-1/2 inches of the tube exposed near the sediment, as evidenced by white etch marks (Figure B-17).

Vinyl Tube (NCEL No. 389). Moderate numbers of small, shallow borer holes were found on the tubing.

0.015-Inch Insulation Over No. 16 Wire

The 15-inch-long stressed and nonstressed silicone-rubber-insulated wire specimens exposed next to sediment and another identical set exposed to sea water about 3 feet above the sediment were deteriorated by marine animals. Microorganisms, amphipods, and crabs found on the STU may have been responsible for the destruction. The specimens of silicone rubber insulation exposed near the bottom were heavily damaged, exposing the bare wire to sea water in several areas (Figure B-18).

Neoprene and GR-S rubber insulations exposed near the sediment were also slightly damaged by the nibbling action of marine animals. However, a set of identical stressed and nonstressed neoprene and GR-S rubber insulation exposed about 3 feet above the sediment were not so damaged.

The stressed and nonstressed polyethylene and polyvinyl chloride insulation exposed near the sediment and 3 feet above the sediment were not damaged.

The results of insulation resistance and voltage breakdown tests on the recovered wire specimens are presented in Table IV. A long-term laboratory study on the effects of deep-sea microorganisms on these rubber and plastic insulations has been reported.[7]

Insulated Cables — Single and Multiconductor

Of the various insulations of varied thicknesses over single and multiconductor wires, the 1/16-inch-thick silicone rubber insulation exposed over the sediment was severely damaged by nibbling and chewing, presumably by amphipods and crabs. Some areas of the insulating material were completely destroyed, exposing the bare wires to sea water (Figure B-18). The silicone rubber insulation exposed about 3 feet above the sediment was also attacked by marine animals but not as severely as the one exposed near the sediment.

A few borers had penetrated slightly into the silicone rubber (Figure B-19) and nylon insulating materials. The borer holes found on the silicone rubber were exposed to the sea-water environment. The borer holes found on the nylon, however, were exposed in an area underneath the wooden bait piece. The bait piece exposed near the sediment was severely damaged compared to the piece exposed about 3 feet above the sediment (Figure B-20).

The cable insulations other than silicone rubber and nylon insulation were not damaged by marine animals or affected by the deep-sea environment.

Table IV. Deep-Ocean Effects on Insulation Resistance of Electrical Insulating Materials

Materials (15 mils thick)	Insulation Resistance (megohms)		Voltage Breakdown 3/
	Before Exposure 1/	After Exposure 2/	
Exposed in Sediment			
Straight Wire			
Polyethylene	20,100,000	335,000	None
Polyvinyl chloride	4,400,000	112,000	None
Silicone rubber	6,200,000	Insulation destroyed	Failed
GR-S rubber 4/ (SBR)	5,500,000	8,300	None
Neoprene	36,000	7,200	None
Coiled Wire			
Polyethylene	20,100,000	1,275,000	None
Polyvinyl chloride	4,400,000	1,250,000	None
Silicone rubber	6,200,000	Insulation destroyed	Failed
GR-S rubber (SBR)	5,500,000	830,000	None
Neoprene	36,000	30,000	None
Exposed About 3 Feet Above Sediment			
Straight Wire			
Polyethylene	20,100,000	138,000	None
Polyvinyl chloride	4,400,000	97,000	None
Silicone rubber	6,200,000	5,200	None
GR-S rubber (SBR)	5,500,000	3,800	None
Neoprene	36,000	17	None
Coiled Wire			
Polyethylene	20,100,000	25,000	None
Polyvinyl chloride	4,400,000	25,000	None
Silicone rubber	6,200,000	25,000	None
GR-S rubber (SBR)	5,500,000	1,700	None
Neoprene	36,000	16,600	None

1/ Average of 8 wires.
2/ Average of 2 wires.
3/ Tested at 1,000 volts AC for 10 seconds.
4/ Government Rubber Styrene (75/25 copolymer of butadiene/styrene).

Wood Specimens

A total of 26 wood test panels including pine, fir, ash, maple, oak, and redwood were exposed to determine the effects of deep-ocean animals on different woods. None of the woods were immune from borer attack — including redwood (Figure B-21), which is considered very resistant to insect attack, such as by termites, as well as to decay.

A majority of the borers had concentrated their attack in large numbers along the inside edge next to the laminated plastic sheet to which the panels were attached. The panels had become saturated with sea water and had warped, producing a thin crevice between the wood and the plastic sheet. Such an area in the crevice would be ideal for borer activity because it would be protected from the slightest amount of sea currents, which the borers seem to dislike.

Very little borer attack occurred on the surface of the 2- by 6-inch wood panels exposed about 3 feet above the sediment, probably because of the presence of currents. The surfaces of only two fir panels and an oak panel facing the sea water were attacked by borers. These panels were exposed at the sediment-water interface and were attached behind the plastic sheet where there was very little current. There was an average of 25 borers per square inch of surface on these panels. Deterioration of the panels was more pronounced where the borers had attacked, in large numbers, over a narrow area along the edges of the panels (Figure B-22). The majority of the borers were 1/16 inch in diameter and had penetrated over 3/16 inch into the wood.

The largest borers were found boring into the ends of a large fir wood bait piece fitted over plastic rods and tubes (Figure B-23). Some of the borers were 1/8 inch in diameter and had penetrated approximately 5/16 inch into the wood. When finally matured, the shells of these borers will grow to about 3/4 inch in diameter. The borers were also present throughout the surface of the pine bait piece fitted around the plastic specimens. In one area of the wood there were approximately 200 young borers in a 1-square-inch area (Figure B-24). The average diameter of entry holes was 1/32 inch. The borers inside the wood were 1/16 inch in diameter and had penetrated approximately 1/8 inch into the wood.

The molluscan marine borers in pine test panels have been identified as <u>Xylophaga washingtona</u> Bartsch[8] (Figures B-25 and B-26).

Unaffected Materials

The borers had failed to penetrate into the following plastics: nylon, phenolic resin, polycarbonate, Teflon, polyethylene, polyvinyl chloride (pipe), and a yellow vinyl. However, there were numerous small circular etched areas on the surface of many of these plastics. These are areas where the borers had attempted to penetrate into the plastic materials but were unable to do so, probably because of the following reasons: (a) very hard surface — nylon, polyvinyl chloride pipe, polycarbonate; (b) waxlike surface — Teflon, polyethylene; (c) soft, flexible, and smooth surface — yellow vinyl tube (NCEL No. 387); (d) thick bacterial slime growth — vinyl tube (NCEL No. 374).

The laminated plastic specimens were not affected by marine organisms (Figure B-27). Metal, glass, and natural and butyl rubber were also immune to attack.

SUMMARY OF FINDINGS — TEST SITE II

The effects of deep-sea fouling and boring organisms on the materials exposed for 197 days on the ocean floor in 2,340 feet of water are summarized in Appendix A. General findings were as follows:

1. There is considerable biological activity in the sediment near Test Site II.
2. There was bacterial slime growth on plastic and rope specimens, nickel-plated shackles, and on aluminum buoys of the STU complex.
3. Specimens of cotton and Manila rope fibers and jute fiber wrapping (burlap) were deteriorated by bacterial action.
4. Various wood panels such as pine, redwood, fir, maple, cedar, ash, and oak were attacked by moderate numbers of marine borers, Xylophaga washingtona Bartsch. Some of the larger borers were about 1/8 inch in diameter and had penetrated about 5/16 inch into the wood. The borers had penetrated slightly into some of the plastic rods and tubes. Manila rope specimens were heavily infested with marine boring animals.
5. The following materials were not affected by marine organisms: metal, glass, natural rubber, and butyl rubber. The following plastics with very hard and smooth surfaces were not affected or were only slightly affected: plastic laminates, Teflon, nylon, phenolic resin, polycarbonate, polyethylene, and polyvinyl chloride.
6. Marine borers were most active in protected areas, such as crevices or along the edges of tape wrappings, where they were apparently sheltered from sea currents.

COMPARISON OF TEST SITES I AND II

A comparison of the biodeterioration reported here of materials exposed at Test Site II (STU II-1) in 2,340 feet of water with that of materials recovered from Test Site I (STU I-3) in 5,640 feet of water (Figure 1), reported in Reference 1, shows some significant differences.

There seem to be more and larger marine animals living in or on the soft bottom sediment at Test Site II than at Test Site I. This observation is evidenced by the number of amphipods and large crabs found on STU II-1 materials when recovered. These

animals were probably responsible for the damage to the silicone rubber insulation at Test Site II. Silicone-rubber-insulated cables exposed on the sediment at Test Site I were not damaged.

Possibly because of its higher water temperature (see Table I), the animals at Test Site II, especially the marine borers, seem to be more active than those at Test Site I. The lower dissolved oxygen concentration found on the sea floor at Test Site II does not seem to have any measurable comparative effect on the animals. The marine borers were found boring into plastic rods, tubes, and tape exposed at Test Site II. No such borer holes were found on identical material exposed at Test Site I. However, the test materials were exposed about 2 months less at Test Site I than at Test Site II.

Manila rope specimens exposed at Test Site II were heavily infested with borers and about 75 percent of the rope's tensile strength destroyed. Manila rope specimens exposed at Test Site I were attacked slightly by few borers, and the rope's tensile strength was not reduced or destroyed.

CONCLUSIONS

The results obtained to date, from 4 and 6 months exposures, on the biological deterioration of engineering materials in the deep ocean indicate that materials such as glass, plastic laminates, plastic ropes, and certain synthetic rubber materials may not be affected; however, additional data from exposures longer than 6 months are needed to provide assurance of relative resistance of these materials to marine organisms.

Because of severe biological deterioration of untreated wood panels (including redwood), jute fiber materials, and cotton and Manila ropes, the use of these materials for deep-ocean applications is not recommended. Electrical cables covered with silicone rubber insulation is not recommended for use on the sea floor in the vicinity of Test Site II, where large deep-sea crabs exist and presumably attack this material.

FUTURE PLANS

Investigation of the effects of the deep-ocean environment upon materials is continuing.

Test Site I (Nominal Depth of 6,000 Feet)

STU I-1 with over 1,000 test specimens exposed on the ocean floor in 5,300 feet of water for a period of nearly 3 years (35 months) was recovered from Test Site I in February 1965. The materials are being examined for corrosion and biodeterioration,

and separate reports of the findings will be issued. Two additional STU's (I-2 and I-4) have been exposed at Test Site I since October 1963 and June 1964 at 5,600 feet and 6,800 feet respectively. They will be recovered later in 1965.

Test Site II (Nominal Depth of 2,500 Feet)

In April 1965, STU II-2 was placed on the ocean floor at this test site. Plans are to retrieve it after a year's exposure at this depth.

REFERENCES

1. U. S. Naval Civil Engineering Laboratory. Technical Report R-329: Deep-ocean biodeterioration of materials — part I. Four months at 5,640 feet, by J. S. Muraoka. Port Hueneme, Calif., Nov. 1964.

2. ______. Technical Report R-369: Design, placement, and retrieval of submersible test units at deep-ocean test sites, by R. E. Jones. Port Hueneme, Calif., May 1965.

3. ______. Technical Report R-182: The effects of marine organisms on engineering materials for deep-ocean use, by J. S. Muraoka. Port Hueneme, Calif., Mar. 1962.

4. ______. Technical Note N-657: Environment of deep-ocean test sites (nominal depth, 6,000 feet) latitude 33°46' N, longitude 120°37' W, by K. O. Gray. Port Hueneme, Calif., Feb. 1965.

5. ______. Technical Note N-695: Examples of corrosion of materials exposed on STU II-1 in the deep ocean (2,340 feet of depth for 197 days), by F. M. Reinhart. Port Hueneme, Calif., Feb. 1965.

6. Society of American Bacteriologists, Committee on Bacteriological Technic. Manual of microbiological methods. New York, McGraw-Hill, 1957.

7. U. S. Naval Civil Engineering Laboratory. Technical Report R-358: Deterioration of rubber and plastic insulation by deep-ocean microorganisms, by J. S. Muraoka. Port Hueneme, Calif., March 1965.

8. Marine borers identified by Dr. Ruth D. Turner. Museum of Comparative Zoology, Harvard University, Cambridge, Mass.

Appendix A

BIOLOGICAL EFFECTS ON MATERIALS ASSEMBLED ON BIO-RACKS

Materials	Information	Summary of Results
Solid Plastic Rods	Commercially available, 3 feet long	
Delrin	3/4-inch diam	Surface etched by borers.
Nylon	3/4-inch diam	Not affected.
Phenolic	3/4-inch diam	Not affected.
Polycarbonate	3/4-inch diam	Not affected.
Teflon	3/4-inch diam	Not affected.
Cellulose acetate	1-inch diam	Borer holes about 1/64-inch deep and 1/32-inch wide.
Polyethylene	1-inch diam	Not affected.
Extruded acrylic	1-inch diam	About 150 borer holes along edge of plastic tape wrapping. Some holes 1/32 inch deep and 1/16 inch wide.
Cast acrylic	1-inch diam	Three borers penetrated into plastic.
Polystyrene	1-inch diam	Twenty-five borer holes in solid plastic along edge of tape wrapping.
Vinyl Plastic Tubes	1-inch OD, 3 feet long	
NCEL No. 374	Flexible low-temp tube — black	Heavy bacterial slime growth over entire surface. Free of borer attack.

NCEL No. 387	Fuel and lubricating tube — yellow	Not affected.
NCEL No. 388	Flexible general utility chemical hose — black	Fifteen borer holes to 1/32 inch deep along edge of tape wrapping. About 150 borer holes per square inch on lower 2-1/2 inches of plastic exposed near the sediment.
NCEL No. 389	Semirigid general utility chemical hose — black	Borer holes in moderate numbers over surface of plastic.
Plastic Pipe		
Unplasticized polyvinyl chloride	1-inch ID, 3 feet long	Not affected.
Rubber		
Rubber vacuum tubing	3 feet long — red	Not affected.
Glass		
Microscope slide		Not affected. Some microscopic fouling organisms on surface of glass.
Ropes	Various lengths	
Cotton	1/2-inch diam	Heavy slime growth. Fibers decayed by bacterial activity.
Manila (hemp)	1/2-inch diam	Heavy slime growth. Usefulness of rope destroyed by marine borers.
Nylon	1/4-inch diam	Slime growth present. Rope in excellent condition.

Materials	Information	Summary of Results
Polypropylene	5/16-inch diam	Slime growth over rope. Rope in excellent condition.
Electrical Cable Insulations	Insulation over single and multiconductor wires 10-inches long	
Butyl jacket		Not affected.
Neoprene jacket		Not affected.
Natural rubber		Not affected.
Silicone rubber	Blue	Insulation destroyed by nibbling and chewing action of marine organisms. Bare wire exposed to sea water in some areas.
Polyvinyl chloride		Not affected.
Vinyl		Not affected.
Polyethylene	Clear low density	Not affected.
Nylon jacket		Several shallow borer holes under pine bait piece.
Teflon		Not affected.
Flourinated ethylene propylene (FEP)		Not affected.
Electrical Insulation	0.015-inch insulation over No. 16 wire 15-inches long	

Straight Specimens		
Silicone rubber		Insulation destroyed by marine organisms. Bare wire exposed to sea water.
GR-S rubber		Surface exposed near sediment slightly eroded in spots by marine organisms
Neoprene rubber		Surface exposed near sediment slightly eroded in spots by marine organisms.
Polyvinyl chloride (PVC)		Not affected.
Polyethylene		Not affected.
Coiled Specimens		Same as above.
Silicone rubber		
GR-S rubber		
Neoprene rubber		
Polyvinyl chloride (PVC)		
Polyethylene		
Wrapping Over Plastic Rods and Tubes		
Plastic insulation tape, electrical	Pressure-sensitive adhesive 0.010-inch thick, 3/4 inch wide — black	Attacked by marine borers in moderate numbers.
Rubber insulation 3/4 inch wide tape, electrical		Slight amount of surface cracking from deep-sea exposure.

Materials	Information	Summary of Results
Jute (burlap)		Slime bacteria over entire surface. Fibers destroyed by bacterial activity. Some borers burrowed into jute fiber.
Wooden Panels	1/2 x 2 x 6-inch panels	All attacked by borers. Some had penetrated over 3/16 inch.
Pine		
Fir		
Maple		
Ash		
Redwood		
Cedar		
Wooden Bait Pieces		
Fir	2-1/2 x 3-1/2 x 30-inch bait piece over plastic rods and tubes	Entire surface riddled by borers. Some borers were 1/8 inch in diameter and had penetrated over 5/16 inch into the wood.
Pine	1 x 1 x 10-inch bait piece over electrical cables	Same as fir bait piece.
Plastic Laminates	1/8 x 1 x about 5 inches	The laminates were not affected by marine organisms. Water absorptions were:
NCEL No. S-5-3	Phenolic resin, fine weave, cotton fabric base; MIL-P-15035B, Type FBG	2.8%

NCEL No. S-7-3	Phenolic resin, fine weave, paper base; MIL-P-3115B, Type PBE	2.1%
NCEL No. S-8-3	Phenolic resin, cotton fabric base; MIL-P-15035B, Type FBG	3.1%
NCEL No. S-9-3	Phenolic resin, nylon fabric base; MIL-P-15047B, Type NBG	1.3%
NCEL No. S-10-3	Melamine resin, glass fabric base; MIL-P-15037B, Type GMG	0.3%
NCEL No. S-11-3	Epoxy resin, glass fabric base; MIL-P-18177, Type GEE	0.2%

Appendix B

EXAMPLES OF SPECIMENS RECOVERED FROM OCEAN FLOOR

Figure B-1. Hydroids on aluminum buoy. Notice the white aluminum corrosion products.

Figure B-2. A 2-inch-long coelenterate, possibly a specie of sea anemone, attached to the aluminum buoy.

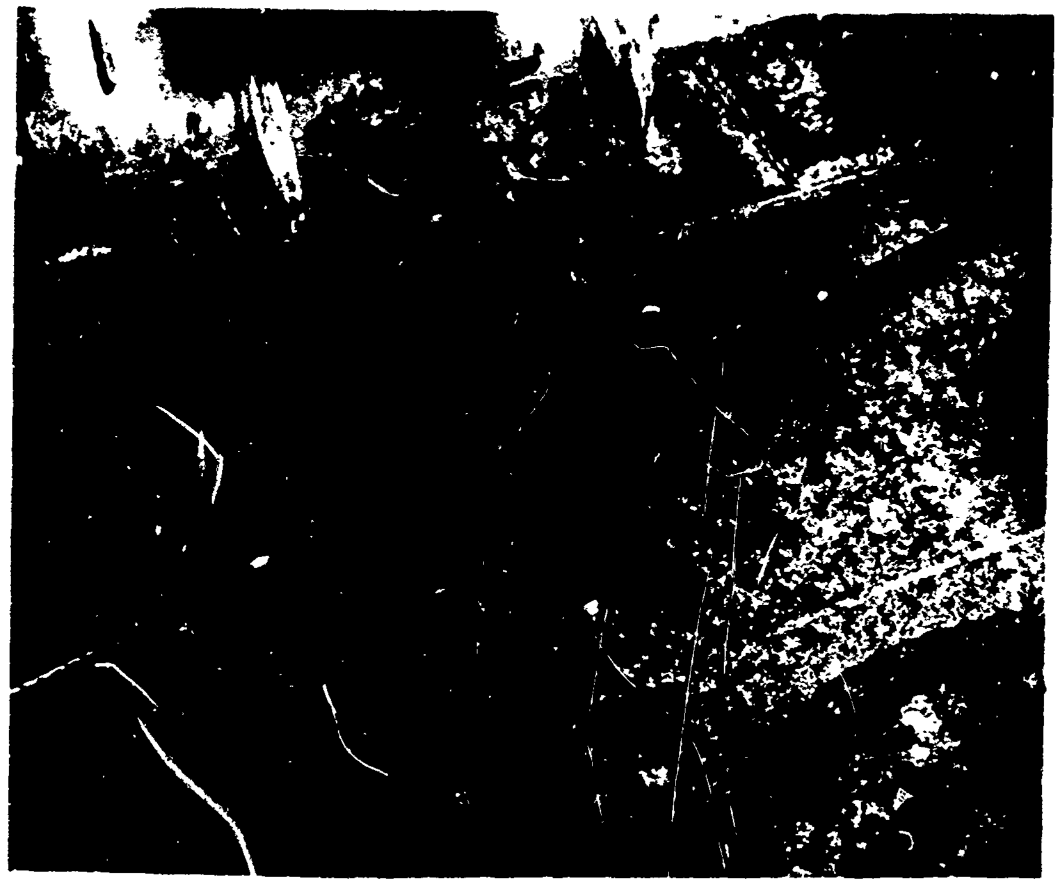

Figure B-3. Sea anemones attached to black polyethylene-covered wire rope.

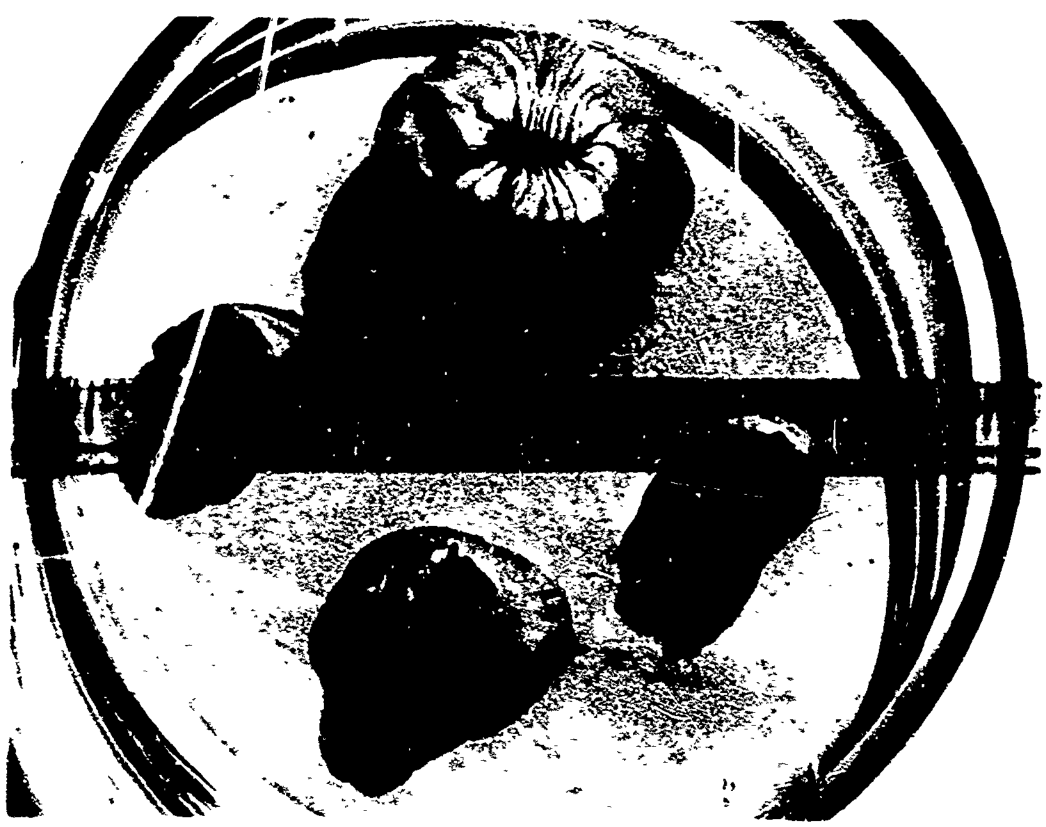

Figure B-4. Close-up view of deep-sea anemones.

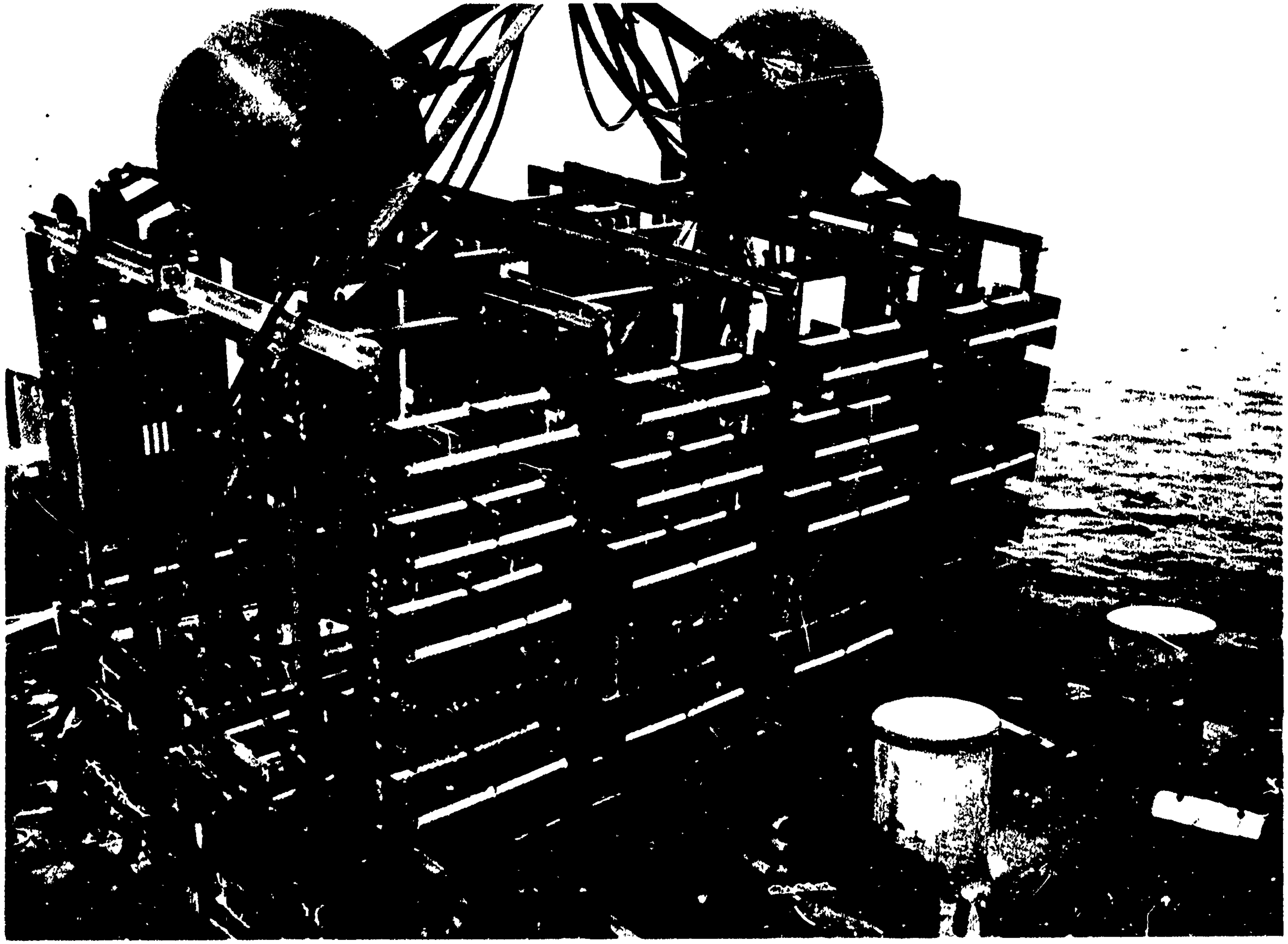

Figure B-5. STU II-1 immediately after recovery from the sea.

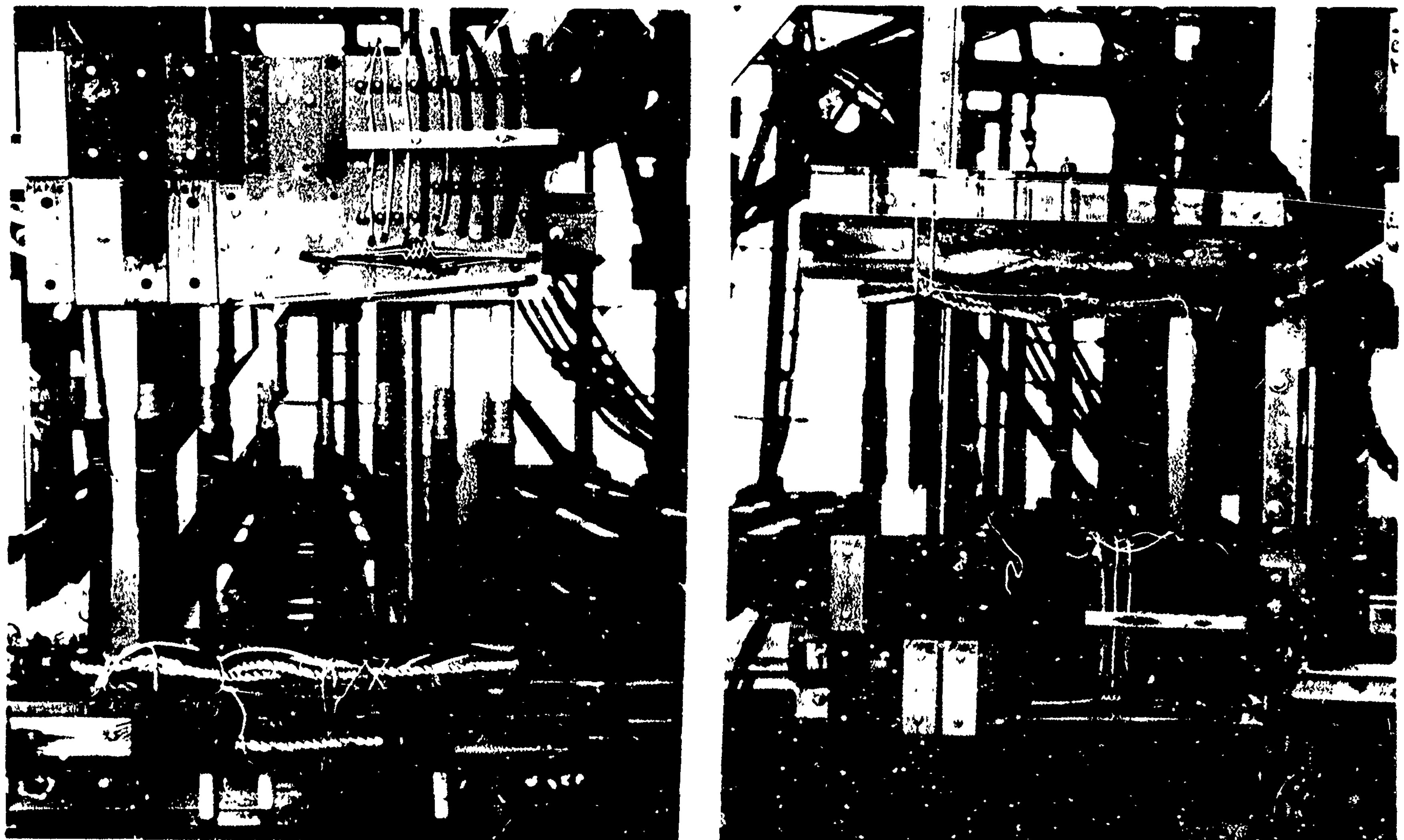

Figure B-6. Biological test specimen racks immediately after recovery from the sea.

Figure B-7. Amphipods found on STU test specimens.

Figure B-8. Deep-sea crabs found crawling over STU test specimens.

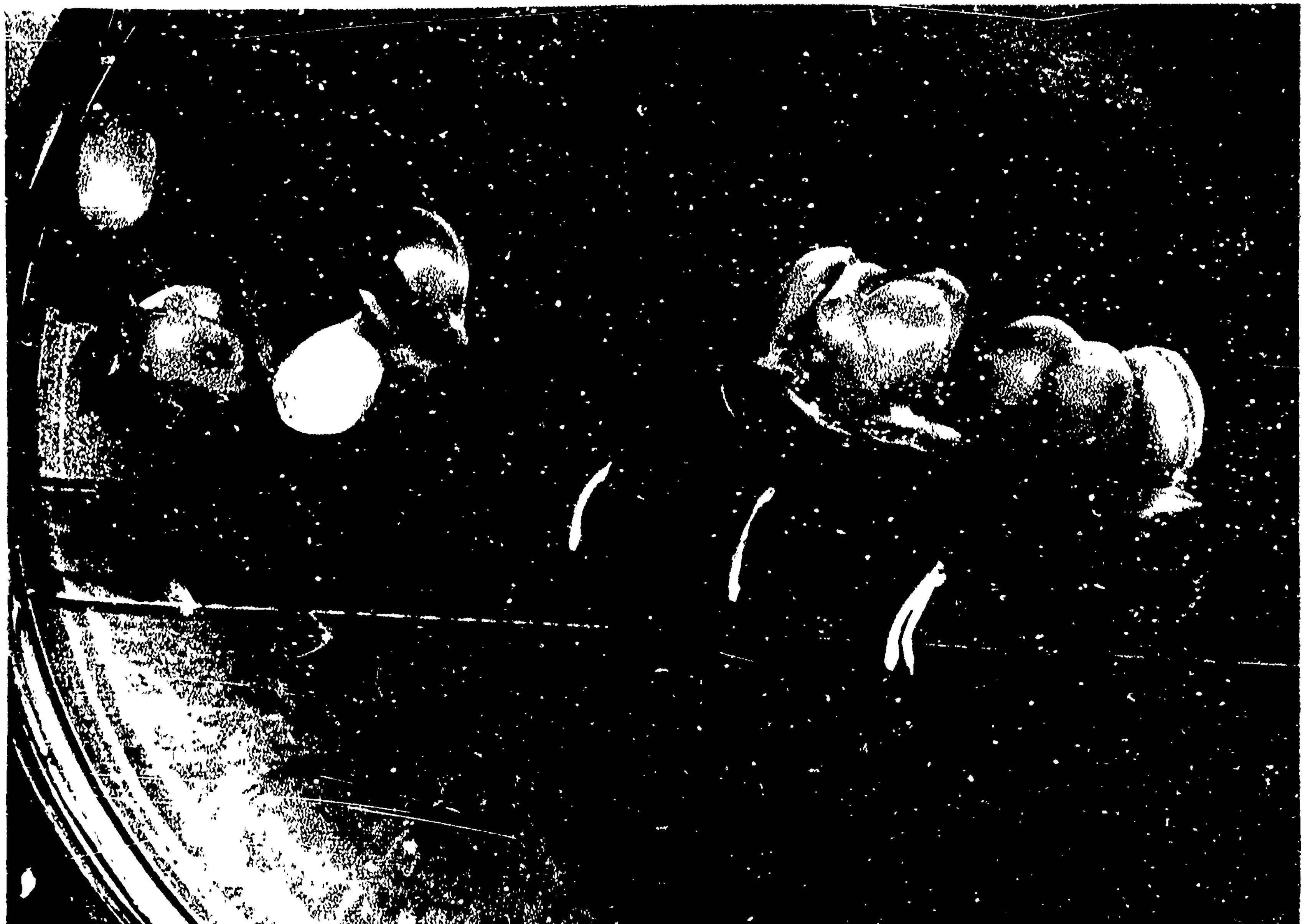

Figure B-9. A colony of fouling growth found attached to the surface of a metal test panel.

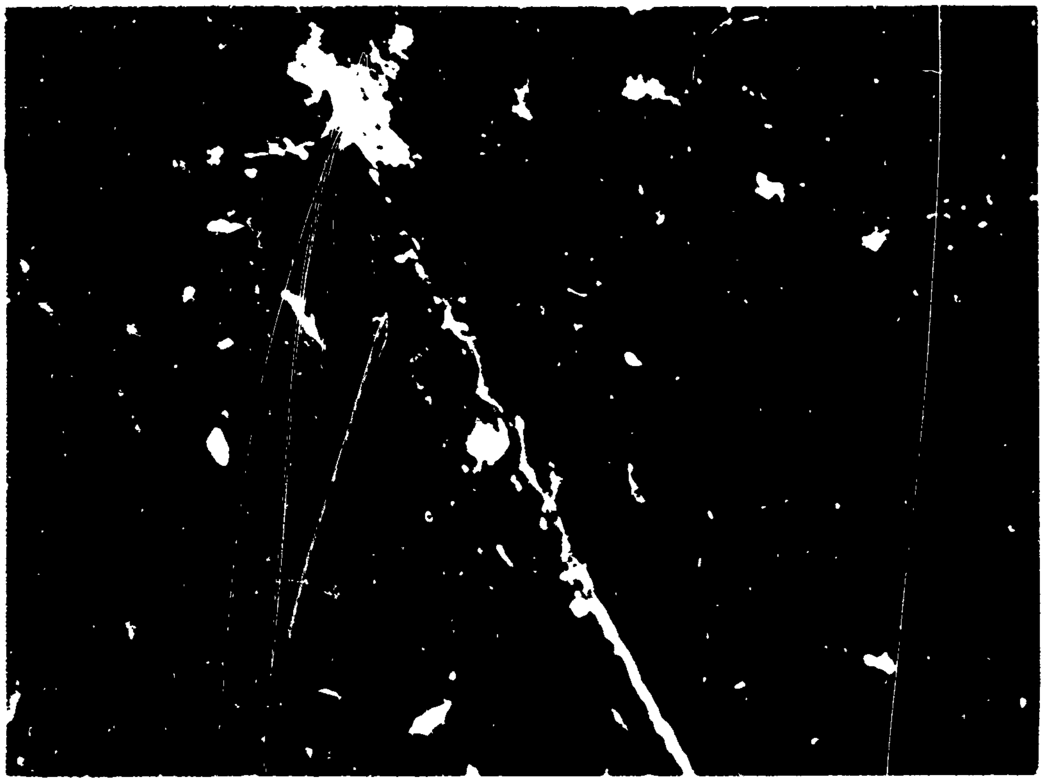

Figure B-10. A marine borer (center) boring into a plastic tape wrapped over plastic rod. (magnified)

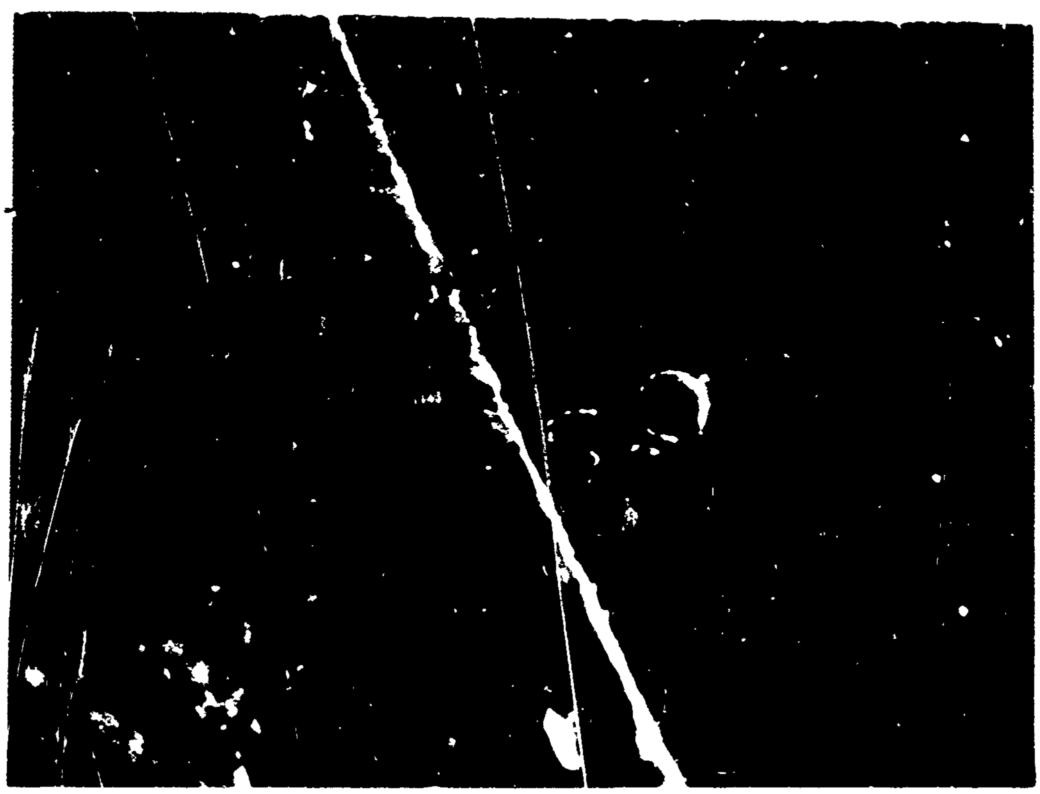

Figure B-11. Borer holes along edge of plastic tape wrapping. A borer had also attempted to penetrate the tape away from the edge. (magnified)

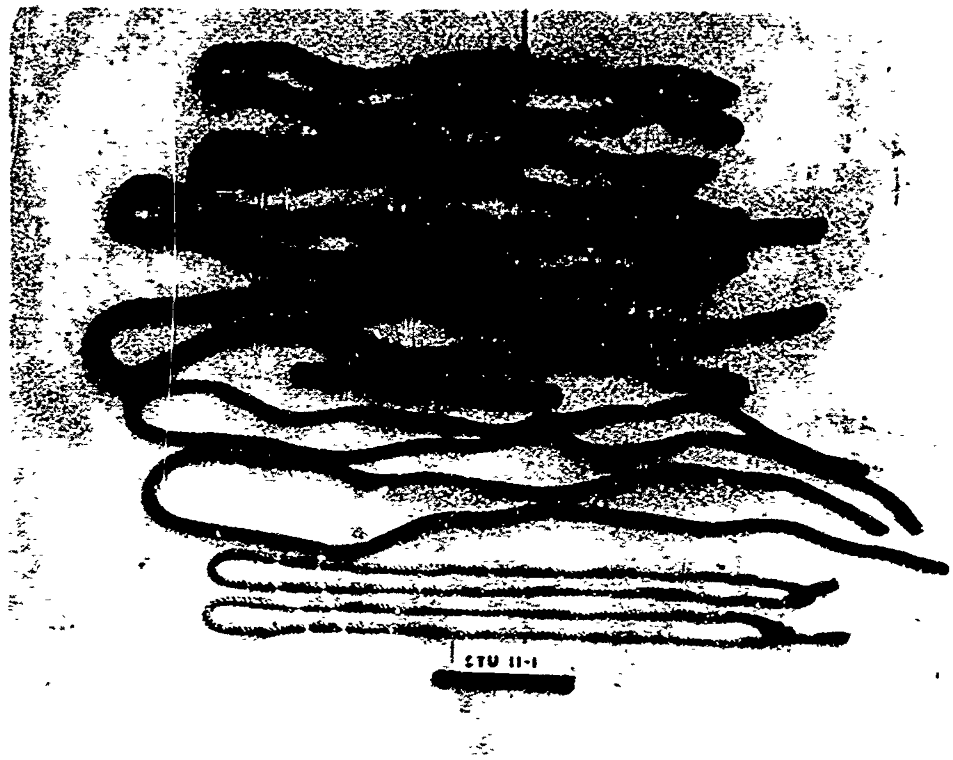

Figure B-12. Cotton, Manila, polypropylene, and nylon rope specimens after recovery.

Figure B-13. Fibers of cotton rope decayed by microorganisms.

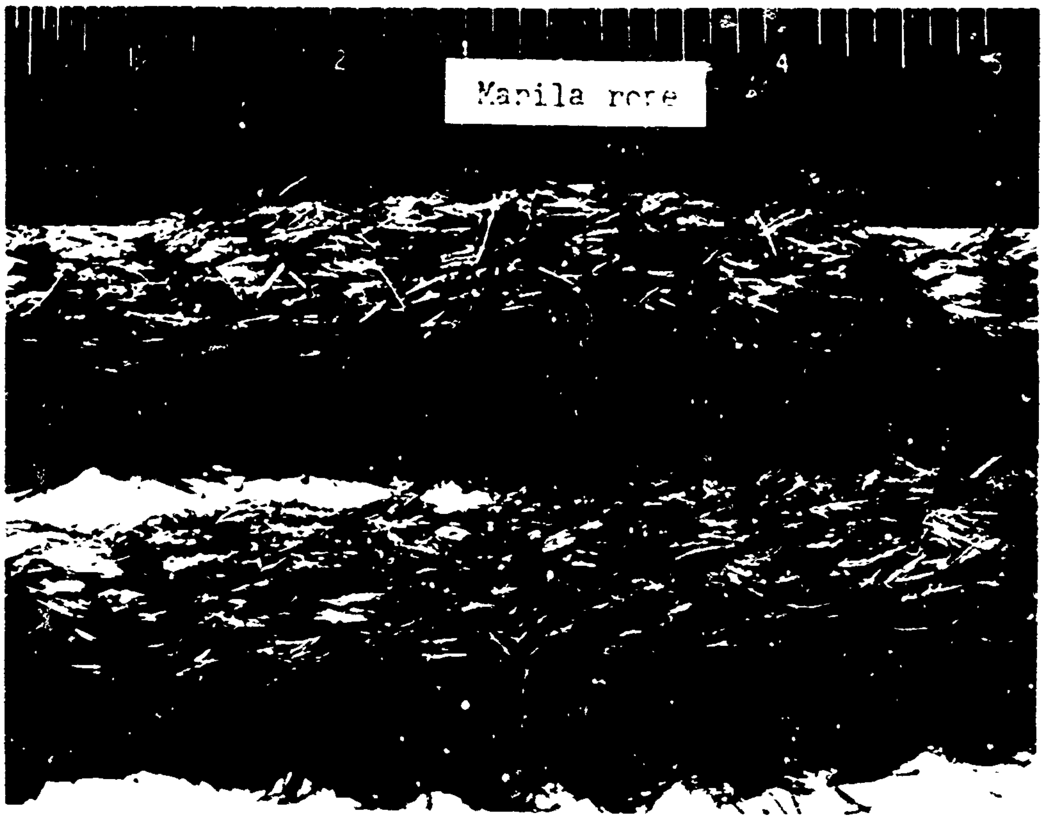

Figure B-14. Fibers of Manila rope destroyed by marine borers. Hundreds of borers are visible on the rope.

Figure B-15. Three-foot-long plastic rods and tubes after 6 months on the ocean floor.

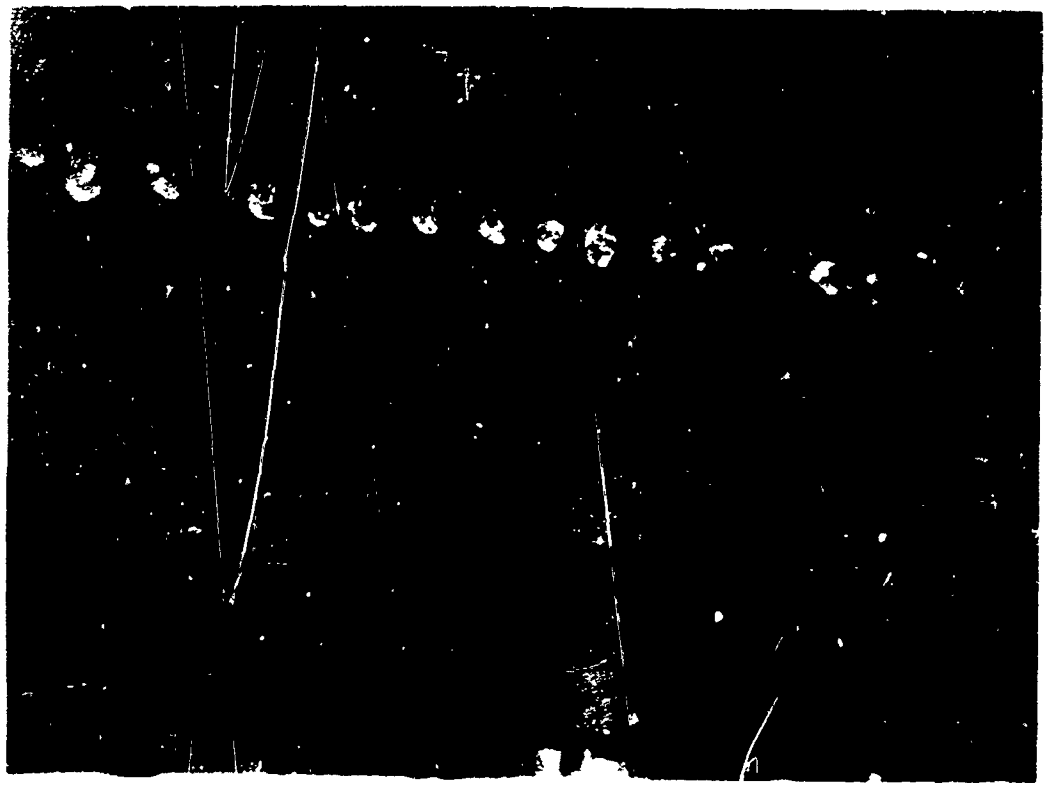

Figure B-16. Small borer holes along edge of plastic tape wrapped around a solid acrylic rod. Tape removed to show holes more clearly. (magnified)

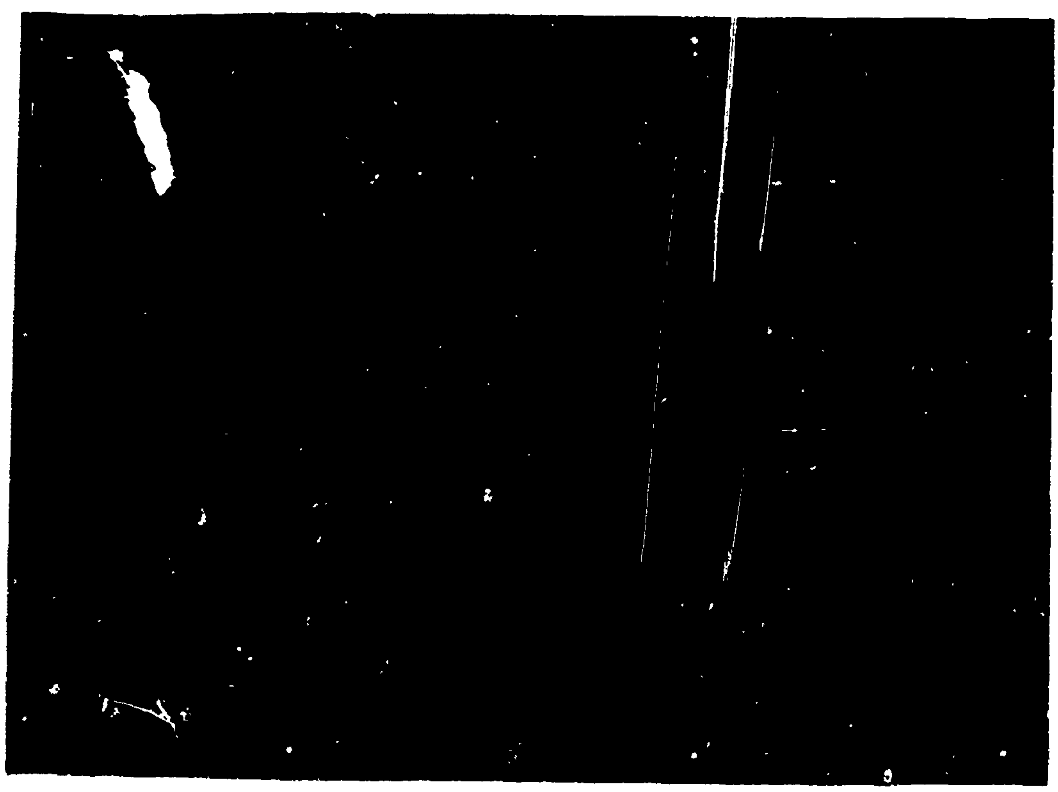

Figure B-17. Etch marks where marine borers had attempted to penetrate into vinyl plastic tube. (magnified)

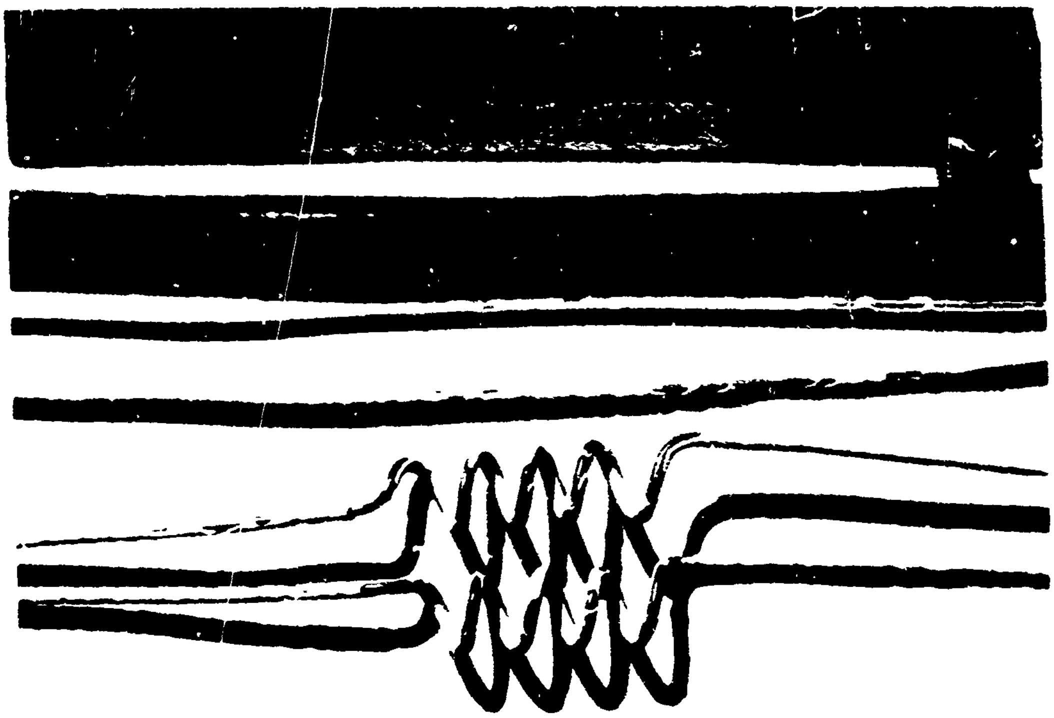

Figure B-18. Wire showing through silicone rubber insulation where the material was deteriorated by nibbling of marine organisms.

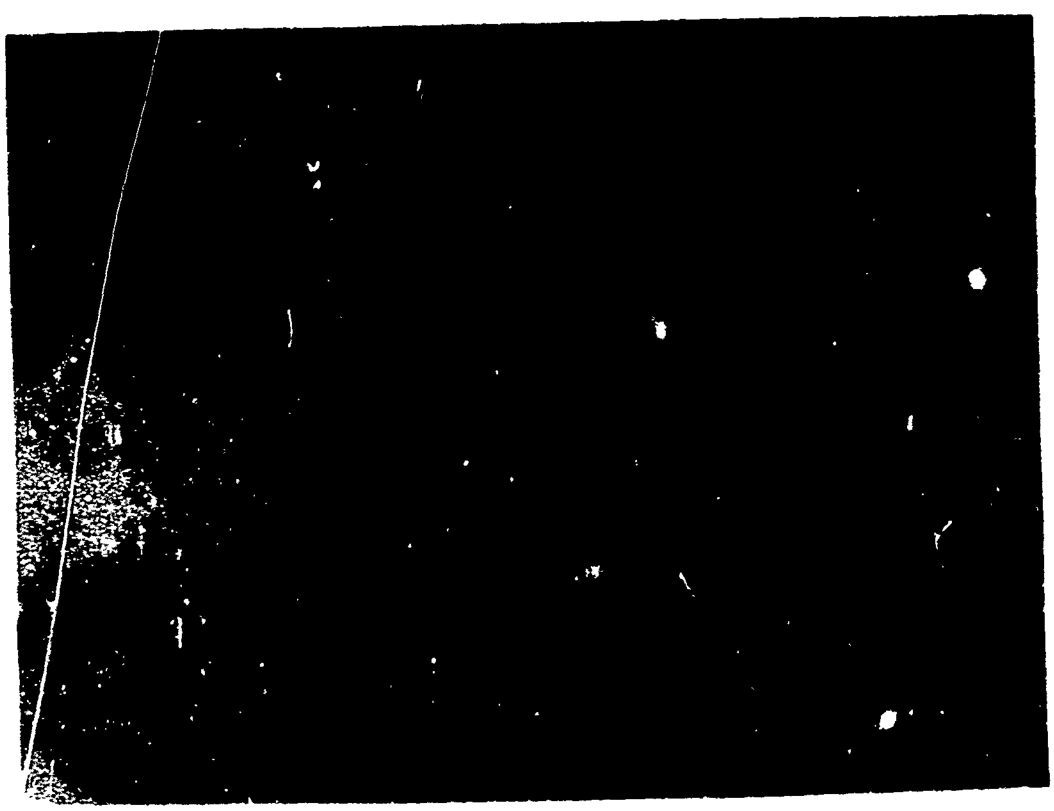

Figure B-19. Shallow holes in silicone rubber made by marine boring animals.

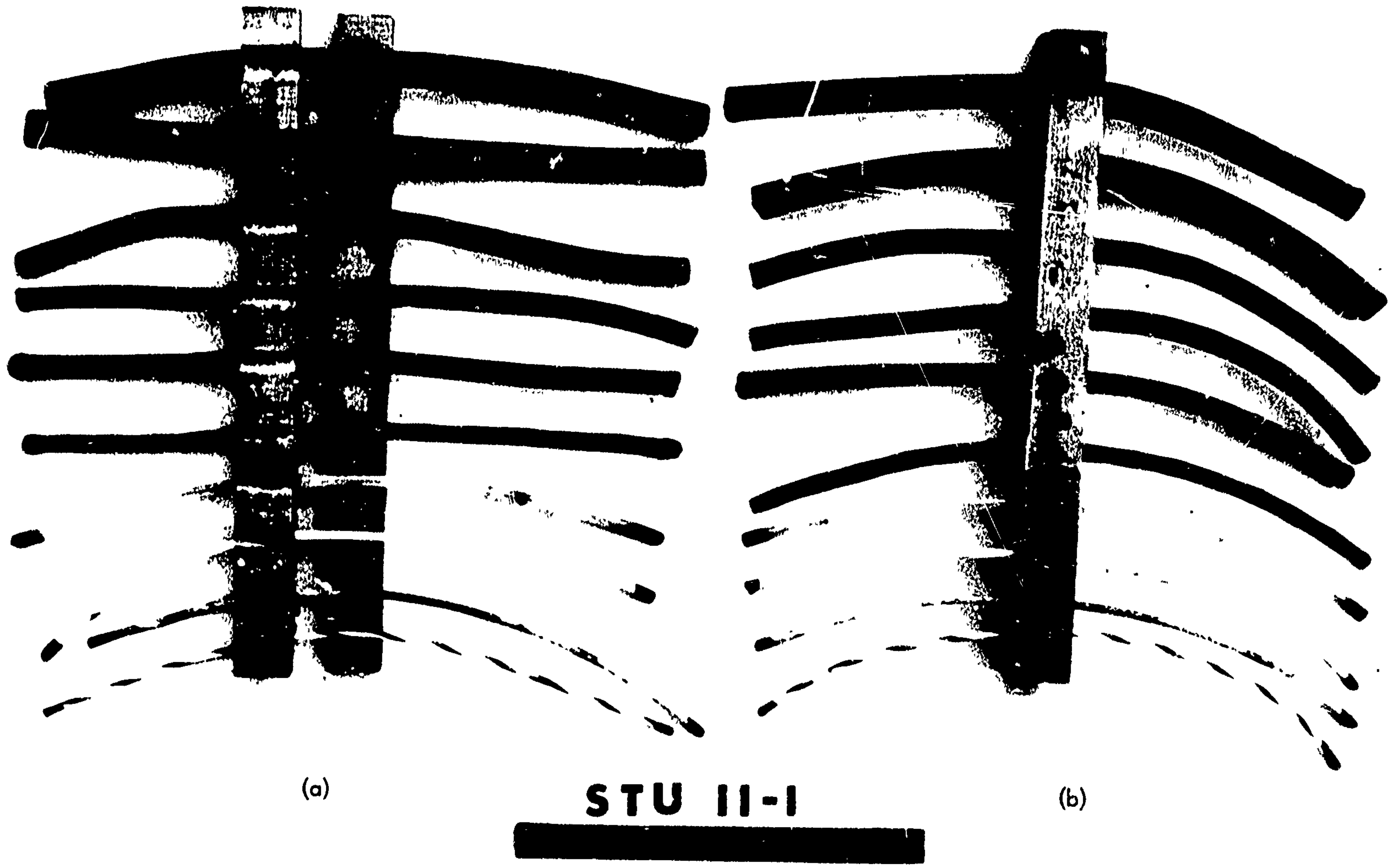

Figure B-20. Electrical cable test specimens showing: (a) numercus borer penetrations of wooden bait piece on specimens exposed near the sediment; (b) slight attack on specimens exposed about 3 feet above the sediment.

Figure B-21. Redwood attacked by Xylophaga washingtona. Some are 1/16 inch in diameter and had penetrated over 3/16 inch.

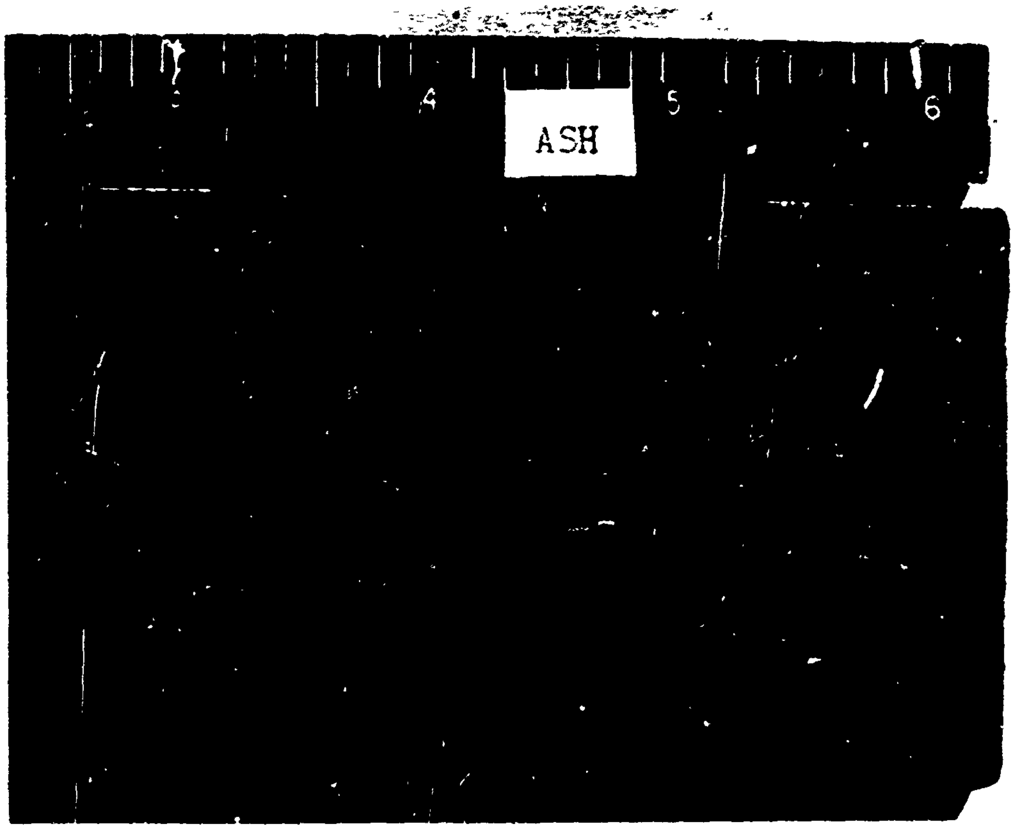

Figure B-22. Marine borers in ash wood panel, along the edge in large numbers.

Figure B-23. Borers in pine wood bait piece for plastic rods and tubes. Some were 1/8 inch in diameter and had penetrated over 5/16 inch.

Figure B-24. Borers in pine wood bait piece. They are concentrated in an area where the rope specimens were resting against the wood.

Figure B-25. Photomicrograph showing borers deep inside pine wood. (magnified)

Figure B-26. Photomicrograph of borers, Xylophaga washingtona. These specimens were about 1/8 inch in diameter. (magnified)

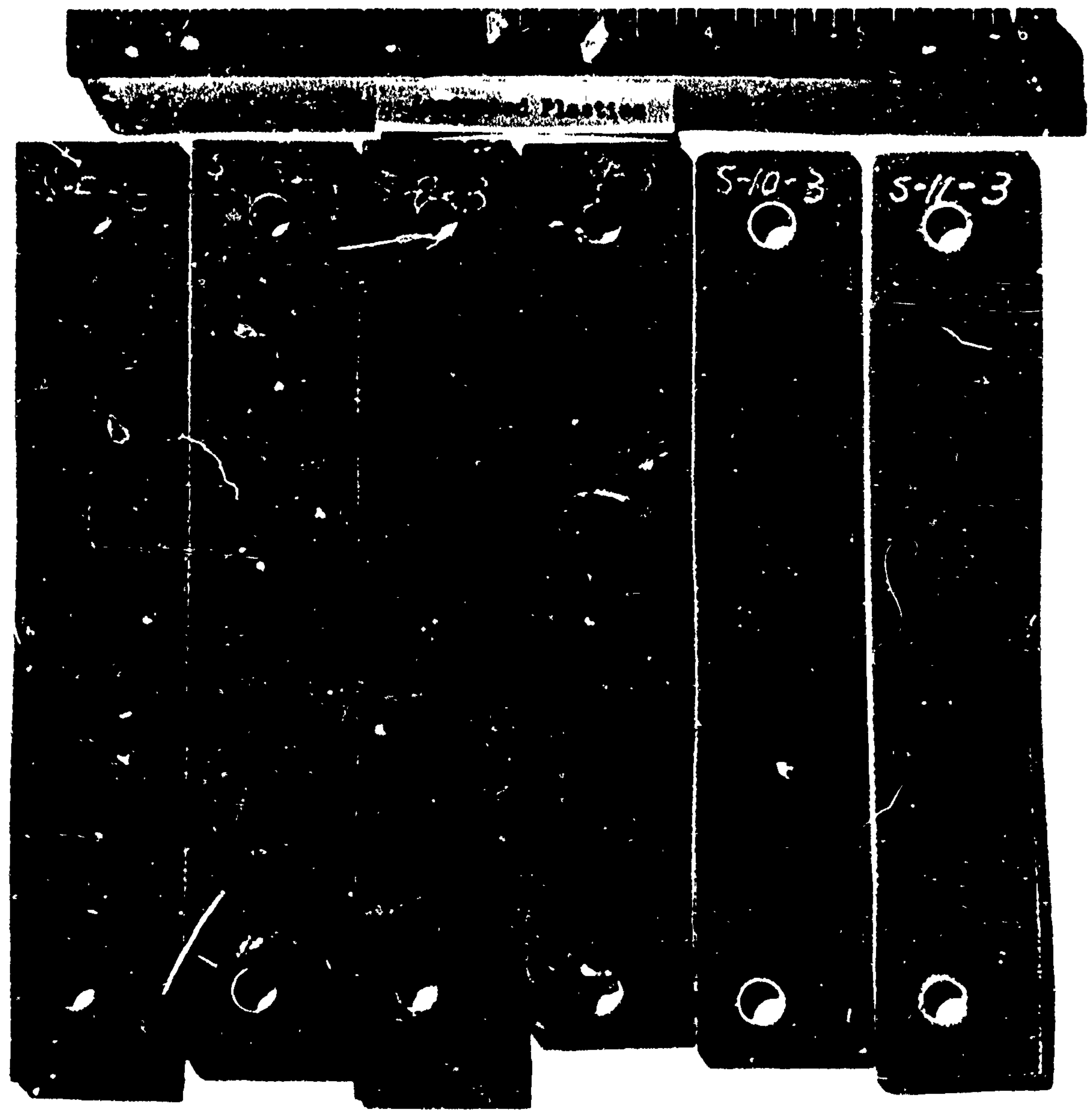

Figure B-27. Laminated plastic test specimens after 6 months on the ocean floor.